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Broadcast Burning: 25-Year Effects on Forest Soils in the Western Flanks of the Cascade Mountains

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ABSTRACT. To determine the long-term effects of broadcast burning on the physical and chemical properties of forest soils, soil samples were collected from paired burned and unburned plots established between 1947 and 1953 after clearcutting in the western Cascade Mountains of Oregon and Washington. Soils were analyzed for organic matter, total nitrogen, phosphorus, potassium, and calcium, as well as permeability and wettability. Results failed to show statistically significant differences between properties of burned and unburned soils, suggesting that broadcast burning does not have a lasting effect on chemical and physical properties of soil. FOREST SCI. 25:427–439.

ADDITIONAL KEY WORDS. Chemical properties, nutrient status, permeability, wettability, fire.

WILDFIRE has been a natural element in the development of many stands in the western Cascade Mountains of Oregon and Washington. Since the advent of forestry practices in the Pacific Northwest, much effort has been directed towards suppressing wildfires. Conversely, forest managers have used prescribed fire after logging for slash disposal and site preparation. The widespread use of prescribed burning has warranted study of its possible impacts on soil nutrients and physical properties. Numerous publications discuss the extremely varied effects of controlled burning and wildfires on forest soils (Kozlowski and Ahlgren 1974). Partly at least, this variation may be explained by the mosaic of conditions, from unburned to severely burned, caused by a fire. Some of the nutrient capital in logging debris, the litter layer, and soil unquestionably volatilizes during controlled burning and later leaches from the ashes.

The loss of organic matter in the soil may be one of the most significant consequences of fire because organic matter plays an extremely important role in maintaining the fertility and favorable physical condition of soils. Slash burning in the Douglas-fir region of Washington (Isaac and Hopkins 1937, Youngberg 1953) and Oregon (Austin and Baisinger 1955, Dyrness and Youngberg 1957) reduced organic matter as much as 75 percent, depending on the severity and soil depth of the burn. The Oregon studies also indicated that organic matter in burned soils builds up slowly—2 years after burning, organic matter in the burned soil was still less than half that in the unburned soil.

Because organic matter contains most of the nitrogen in soils, burning affects both similarly. Severe burning that destroys large amounts of organic matter

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generally volatilizes substantial nitrogen as well. Isaac and Hopkins (1937) estimated that slash burning consumed 487 kg ha^{-1} of nitrogen from their study area. Grier (1975), investigating nutrient losses from the Entiat fire in north-central Washington, reported 855 kg/ha of total nitrogen lost as a result of volatilization and ash convection.

The effects of burning on available nitrogen in forest soils still need further clarification. Fowells and Stephenson (1934) concluded that burning stimulates nitrification in forest soils by liberating basic ash materials. Neal and others (1965) observed a significant increase in ammonium nitrogen (NH_4) for 6 months after burning but no increase in nitrate nitrogen (NO_3). Burning experiments in the laboratory (Knight 1966) indicated that loss of nitrogen from the forest floor by volatilization increases from 25 percent at 300°C to 64 percent at 700°C. Although the total amount of nitrogen decreases, burning increases the nitrogen concentration of the residual material. This phenomenon may explain reports, cited by Moore and Norris (1974), of increased nitrogen after burning.

Burning increases amounts of available nutrients because combustion releases nutrients and most, except nitrogen, remain in the ash. Austin and Baisinger (1955) documented large increases in available phosphorus, exchangeable potassium, calcium, and magnesium in the surface soil soon after burning. Grier and Cole (1971) and Grier (1975) showed that burning substantially increased both the concentrations of ions entering the soil and the loss of ions from the rooting zone.

All these studies indicate that burning significantly changes the nutrient status of the upper layer of soil. The results also suggest that some nutrients return to preburning concentrations within about 2 years, but how long the entire system takes to regain equilibrium remains open to question.

Burning affects physical properties of soils, especially those influencing movement into and through soils. Infiltration rates decreased in severely burned soils of Douglas-fir forests (Tarrant 1956). Elsewhere, severe burning substantially reduced the moisture-holding capacity, possibly by adversely affecting the structural stability, of the uppermost layer of soil (Austin and Baisinger 1955, Dyrness and others 1957).

Apparently another consequence of burning, the formation of a water-repellent layer in the soil, occurs commonly in the western United States (DeBano 1969). DeBano and Krammes (1966) proposed that organic hydrophobic substances at the soil surface vaporize during fire, then condense in the cooler soil underneath. Savage and others (1969) went further, suggesting that organic materials in the heated litter layer pyrolyze, then condense in the cooler parts of the soil.

Later Savage and his coworkers (1972) identified materials like aliphatic hydrocarbons as the effective water-repellent substances in the products derived from heating the litter layer. For 6 years, Dyrness (1976) followed how wildfire in the Willamette National Forest affected soil wettability. Burning apparently increased water repellency of the soil at depths of 2.5 to 22.5 cm, and repellency persisted for 5 years after the fire. DeByle (1973), however, was unable to detect water repellency of soils in Montana for more than 1 year after slash burning. Apparently, both intensity of burn and nature of soil determine how long such effects will last.

Still unknown is how long broadcast burning affects nutrient status and physical properties of forest soils. Plots in a study initiated in 1947 by Morris (1970) provided us with a chance to sample soils burned 25 years earlier and their unburned counterparts (Fig. 1) and to quantify their phosphorus, potassium, calcium, nitrogen,[1] organic matter, infiltration rates, and wettability.

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[1] All references to nitrogen indicate total N unless specified otherwise.

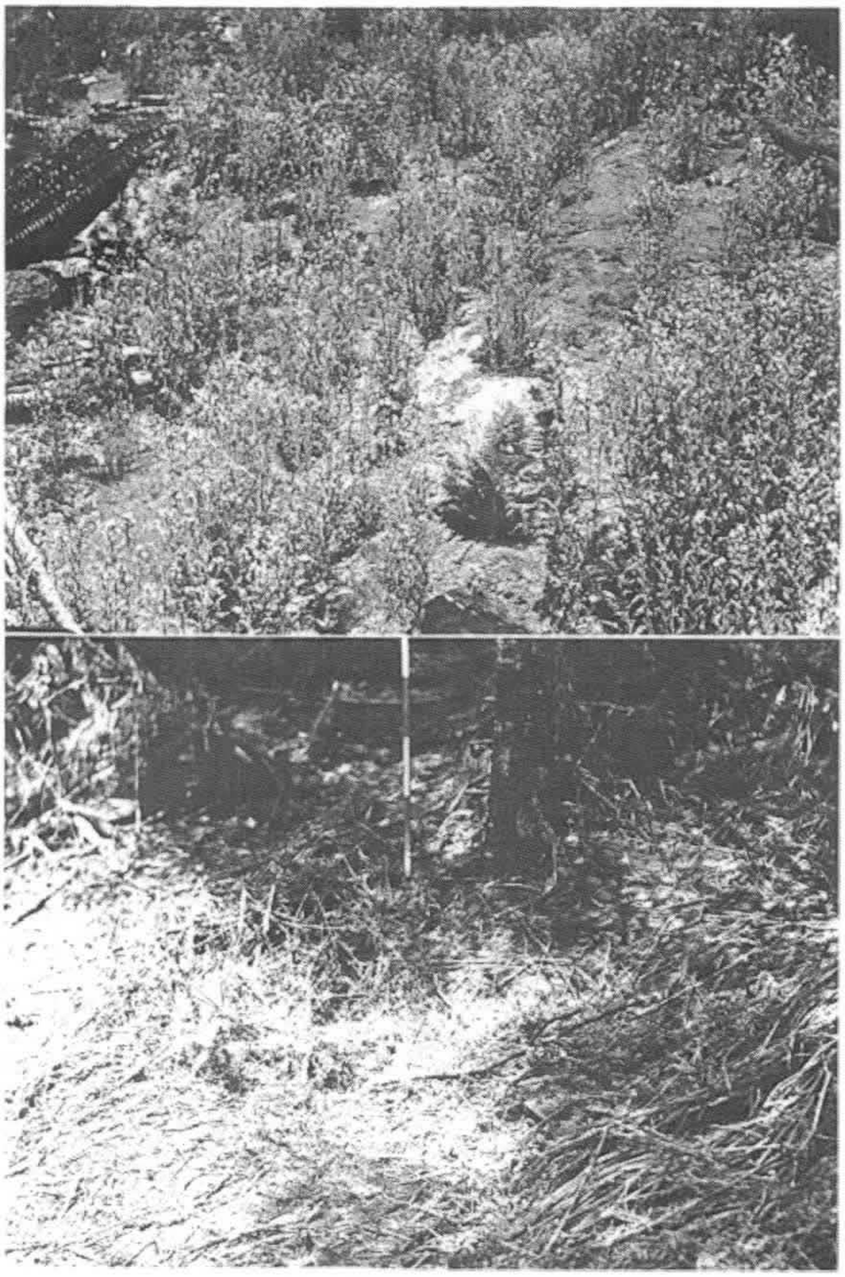

FIGURE 1. Top: severely burned area in 1950, 1 year after burning. Bottom: same area in 1976. Burned log at upper left is still identifiable after 26 years.

Morris had established 62 paired rectangular plots, varying from 0.10 to 0.52 ha, between 1947 and 1951 in western Washington and Oregon. All plots were on commercial logging units "to be burned in the normal slash disposal process," so long-range effects on development of vegetative cover and changes in fire risks could be determined. Although not specified by Morris, burning was probably broadcast. Morris located a line transect across each plot and recorded the in-

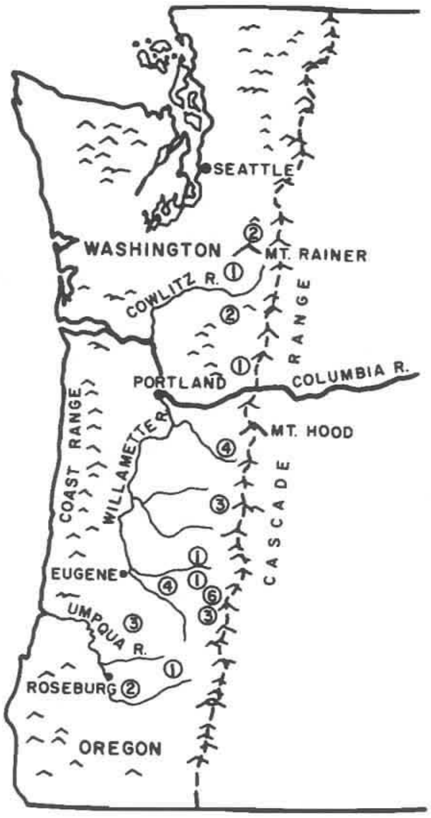

FIGURE 2. Locations of 34 pairs of burned and unburned slash plots in the Douglas-fir region of western Oregon and Washington. Numbers in circles indicate number of plot pairs.

tervals of transect intercepted by any of four classes of severity of burn: unburned, lightly burned, moderately burned, and severely burned. Most pairs were re-examined annually to 1953, and again in 1962, for different categories of fuel, plant cover, and exposed mineral soil. Morris (1970) concluded that burning had greatly reduced probable rate of spread and resistance to control of subsequent fires for 5 years and had changed species composition of brush and herbage; however, burning had no effect on natural regeneration of commercial conifers.

Detailed survey records kept by Morris enabled us to relocate line transects and to identify the portions assigned to the four classes of burn. The principal problem for us was the fact that Morris had not made any soil analyses. Therefore, we proceeded on the assumption that, by comparing the results for burned soils with those from the unburned counterparts, we could check whether the physical and chemical properties of the soils were affected by broadcast burning.

METHODS

Plot Selection.—In 1975, the U.S. Forest Service cooperated with Oregon State University to relocate the 62 pairs of plots—53 in the western Cascades of Oregon and Washington and 9 pairs in the Oregon Coast Range—established by Morris. For our study, we examined the plots and selected those that met these criteria: (1) the area of unburned soil on burn plots had to be less than 30 percent of total area of the plot; (2) if a plot had been either planted or thinned after burning, its paired plot had to have been treated similarly; (3) paired plots had to have comparable aspects and slopes. In addition, we eliminated plots treated with herbicides because such vegetational changes cannot be meaningfully related to the original burned or unburned treatment.

These criteria eliminated all but 34 satisfactory pairs of plots in the Cascades (Fig. 2). Since their establishment, 5 pairs had been planted, 7 had been thinned, 1 had been planted and thinned, and 21 remained untreated.

Soil Nutrient Status.—On burned plots, we took six samples, two each from areas with severely, moderately, and lightly burned soil. We sampled severely burned soil only on those 0.1-ha plots where severely burned soil exceeded 5 percent of the total area because even a small error in distance measured along the transect might result in sampling a soil from a different burn class. Lightly and moderately burned soil posed fewer sampling problems because more of the total plot area occurred in these burn classes.

To locate sampling sites, we used line-transect records, which indicated degree of burn, from the year of plot establishment. For selecting sites on severely burned soil, we supplemented line-transect records with photographs made the year of plot establishment. We had planned to sample only in areas not under a canopy of brush, hardwoods, or conifers because nutrients released from a layer of litter could have obscured burning effects. In many instances, such restriction was impossible, so we sampled in areas as similar as possible in canopy and litter type to equalize the litter effect for samples in each of the burn classes on a plot.

We collected a total of 232 samples from the different soils:

Condition of soil	*Samples*
Unburned	68
Burned:	
Light	67
Moderate	58
Severe	39

Each sample, collected with a 200-cm^3 cylinder from the top 10 cm of soil after debris and the litter layer were removed, was air-dried, passed through a 5-mm sieve to remove coarse material, then passed through a 2-mm sieve and bagged. Extractable P, exchangeable K, exchangeable Ca, N, and organic matter were analyzed by the Soil Testing Laboratory, Oregon State University, Corvallis.

Soil Physical Properties.—Using the same criteria as those for collecting soil samples, we selected a total of 74 samples and measured permeability with an air permeameter:

Condition of soil	*Samples*
Unburned	22
Burned:	
Light	21
Moderate	19
Severe	12

At each sample location, we took five readings at equal intervals along the perimeter of a circle about 0.67 m in diameter whose center was the site of the soil sample. The nozzle of the permeameter was placed flush with the ground while nitrous oxide gas was forced through its orifice into pore spaces in the soil. Soils with high permeability showed small resistance to the gas flow and, thus, a low reading (registered as kilograms per square centimeter) on the permeameter's gauge. Conversely, compacted soils or those with low permeability and more resistance gave high readings. The permeability for a soil sample was the average of the five readings.

For those samples with an adequate volume of soil remaining after nutrient analysis, we determined "wettability," the relative hydrophobic or hydrophilic properties of a soil. Those properties can be correlated with the liquid-solid contact angle—a drop of water placed on a hydrophobic surface balls up, and the liquid-solid contact angle is large. The converse is true for hydrophilic surfaces.

We slightly modified the capillary-rise method (Letey and others 1962) to determine liquid-solid contact angles for 125 samples:

Condition of soil	*Samples*
Unburned	33
Burned:	
Light	30
Moderate	27
Severe	35

For each sample, air-dried soil was packed to equal densities in two glass tubes 8 to 9 mm in diameter. The lower end of one column was vertically immersed in water and the other in ethanol for 18 hours. The heights of the wetting fronts of water and ethanol were measured, and the liquid-solid contact angle was calculated as:

$$\text{Cos angle} - 0.3961 \, \frac{\text{water height}}{\text{ethanol height}} \, .$$

Analyses.—The sampling procedures used for this study had to be developed within the framework of the initial study design prepared by Morris. Because burn intensity was recorded only for the area immediately beneath the line transects, only a small proportion of each plot was available for sampling known types of burn. This constrained the statistical design for analyzing the data. The results in Tables 1–6 were derived using the SPSS statistical computer program (Nie and others 1970).

Soil resource inventories for each of the national forests in the study area described texture, fertility, drainage, infiltration, and substrate properties of our plots. Based on this information, the plots fell into two broad groups. The six plot pairs located north of the Columbia River were designated as soil group 1 with well-drained sandy soils, rapid infiltration rates, and low to moderate fertility; this group overlay a highly variable bedrock material. The remaining 28 plot pairs located south of the Columbia River became soil group 2 with well-drained loam soils, moderate to rapid infiltration rates, and moderate to high fertility; most plots overlay tuffs, breccias, and volcanic sediments, but several plots were on undifferentiated bedrock.

To determine whether any differences in physical or chemical properties of the soils were still evident between burned and unburned plots, we developed weighted plot means for each soil property on individual burned and unburned plots. Values for soil properties were weighted by the percentage of area found in each of the four burn classes, as indicated by the original line-transect record. For example, the weighted mean value of total nitrogen on a burned plot that was 15-percent severe burn, 25-percent moderate burn, 45-percent light burn, and 15-percent unburned area was calculated as: 0.15 × (average N of the two samples taken from severely burned soil) + 0.25 × (average N of the two samples taken from moderately burned soil) + 0.45 × (average N of the two samples taken from

TABLE 1. Chemical and physical properties of soil on burned and unburned plots. All values are weighted means averaged for all plots in a soil group.

Soil group and type of plot	Permeability	Liquid-solid contact angle	P	K	Ca	N	Organic matter
	kg/cm²	*degrees*	*ppm*	*ppm*	*meq/100 g*	*percent*	*percent*
Group 1—North Cascades (6 plots)							
Unburned	([a])	72	380	92**	2.4**	0.10**	5.7**
Burned	([a])	73	380	84**	3.0**	0.09**	7.2**
Group 2—South Cascades (28 plots)							
Unburned	0.745	73	291	501	13.1	0.31	14.7
Burned	0.660	73	360	525	15.6	0.33	14.4

[a] Data insufficient for analysis.

** Significantly different ($P = 0.01$) from the corresponding value in group 2.

lightly burned soil on the unburned member of a plot pair) + 0.15 × (average N of the two samples taken from unburned soil) = weighted plot mean of N for the burned member of a plot pair. We averaged the two samples taken on the unburned member of a plot pair to generate the mean nutrient value for unburned plots—weighting was unnecessary.

For each of the two soil groups, we analyzed soil wettability, permeability, P, K, Ca, N, and organic matter for significant differences between burned and unburned plots.

Next, we analyzed weighted plot means by comparing: severe and moderate burn combined on >25 percent of total surface versus <25 percent; thinned versus unthinned; and with *Ceanothus* cover dominant in 1963, 1975, or both versus without *Ceanothus*. The burned and unburned plots were analyzed separately. Insufficient sample size prevented data analysis for soil group 1. However, for soil group 2, the unburned member of the plot pairs with burned surface area >25 percent was compared with the unburned member of the plot pairs to serve as a check that nutrient differences were attributable to the burning treatment and not to site differences. Likewise, because *Ceanothus* cover was light on unburned plots, the unburned member of the plot pairs dominated by *Ceanothus* was compared with the unburned member of the plot pairs without *Ceanothus*.

In a third step, we compared physical and chemical properties of soils on the four types of burn. We separately grouped data from unburned, lightly burned, moderately burned, and severely burned samples and tested the sums of the four types of burn against one another for each soil property.

Frequently, severe burns occurred under large logs that did not completely contact the ground during broadcast burning. On some plots, however, soil under logs was the only place where we could sample the severely burned condition. To determine whether this influenced results, we compared levels of P, K, Ca, and N between samples from severely burned soil taken under upturned logs and in locations exposed to litter fall and precipitation.

As a fourth step, soil properties were tested for significant differences, calculated by type of burn, within these categories: plots with >25 percent and <25 percent of the surface area moderately and severely burned (combined); thinned versus unthinned plots; and plots with and without dominant *Ceanothus*. Values for each variable were summed for individual types of burn and tested against each other.

TABLE 2. Chemical and physical properties of soil on plots by amount of severe burn, thinning treatment, and dominant cover. All values are means averaged for all plots in grouping.

Plot grouping	Permeability	Liquid-solid contact angle	P	K	Ca	N	Organic matter	Sample size
	kg/cm²	*degrees*	*ppm*	*ppm*	*meq/100 g*	*percent*	*percent*	*number*
>25 percent vs. <25 percent moderate + severe (M + S) burn								
Burned plots								
>25 percent M + S burn	(a)	73	406	685	18.5*	0.34	14.0	12
<25 percent M + S burn	(a)	72	332	350	11.1	0.31	15.4	8
Unburned plots paired with plots having								
>25 percent M + S burn	(a)	77	299	641	14.4	0.32	13.8	12
<25 percent M + S burn	(a)	72	303	360	11.0	0.28	13.4	8
Thinned vs. unthinned								
Burned plots								
Thinned	0.576	72	332	498	16.6	0.32	11.6	7
Unthinned	0.506	74	358	662	17.9	0.33	12.3	9
Unburned plots								
Thinned	0.499	65	283	470	14.5	0.32	17.3	7
Unthinned	0.597	73	343	682	15.6	0.31	10.7	9
Ceanothus vs. no *Ceanothus*								
Burned plots								
Ceanothus	0.527	75	378	395	13.3	0.36	18.2	10
No *Ceanothus*	0.611	73	328	775	17.8	0.31	12.2	8
Unburned plots paired with plots having								
Ceanothus	0.773	75	262	319	9.9	0.31	15.8	10
No *Ceanothus*	0.717	77	275	761	15.0	0.31	12.6	8

[a] Data insufficient for analysis.

* Significantly different ($P = 0.05$) from <25 percent M + S.

As a fifth step, we pooled data from lightly, moderately, and severely burned samples for each variable of a plot group to determine whether their means differed significantly.

In a sixth step, we used the means generated by the previous analysis (step 5) to test for differences between burned members of plot pairs for the groupings by combined area of moderate and severe burn, thinning, and *Ceanothus* cover. The unburned members of the plot pairs were also tested to check for significant differences attributable to the grouping rather than the treatment.

RESULTS AND DISCUSSION

Apparently revegetation of plots burned nearly three decades ago has replenished organic matter lost from the soil through burning. Organic matter in the soils of the two study groups—one in the northern and one in the southern Cascade Mountains—differed significantly only on a geographic basis.

This finding led us to expect that decomposition of organic residues and fixation of atmospheric nitrogen in the period since burning had compensated for nitrogen lost by burning.

TABLE 3. Mean values of chemical and physical properties of soils with different degrees of burn.

Soil group and type of burn	Perme-ability	Liquid-solid contact angle	P	K	Ca	N	Organic matter	Sample size
	kg/cm²	*degrees*	*ppm*	*ppm*	*meq/100 g*	*percent*	*percent*	*number*
Group 1—North Cascades (6 plots)								
Unburned	(a)	72	380	92	2.4	0.10	5.7	12
Burned								
Light	(a)	74	379	81	3.2	0.09	7.5	12
Moderate	(a)	67	436	106	3.3	0.10	5.1	8
Severe	(a)	63	715	100	2.7	0.08	3.7	2
Group 2—South Cascades (28 plots)								
Unburned	0.745	73	291	501	13.1	0.31	14.7	56
Burned								
Light	0.660	74	351	517	15.4	0.34	15.4	55
Moderate	0.695	73	370	501	15.0	0.33	14.2	48
Severe	0.703	73	318	472	14.3	0.25	12.6	24

[a] Data insufficient for analysis.

Our first analysis (Table 1), comparing burned with unburned plots, failed to show any differences except between plots north and south of the Columbia River. This pointed to inherent differences in soil properties of these locations.

Our second analysis—comparing plots grouped according to percentage of combined surface area of severe and moderate burn, thinning treatment, and presence or absence of *Ceanothus* cover—did not show any significant differences (Table 2). The only exceptions were Ca levels in the comparison between plots with >25 percent and <25 percent of the surface area moderately and severely burned combined.

Considerably increased levels of cations in the surface soil are common after burning. Austin and Baisinger (1953) and Grier (1975) have extensively documented this phenomenon for forest soils of the Pacific Northwest. However, we were unable to demonstrate such an effect or severe imbalances in mineral nutrients 25 years after broadcast burning.

TABLE 4. Mean values of chemical and physical properties in severely burned soils sampled under upturned logs and in exposed locations.

Sample locations	Perme-ability	Liquid-solid contact angle	P	K	Ca	N	Organic matter	Sample size[a]
	kg/cm²	*degrees*	*ppm*	*ppm*	*meq/100 g*	*percent*	*percent*	*number*
Under upturned logs	11.6	67.4	47.0*	713*	21.1*	0.19*	5.5	15
Exposed to litter fall and precipitation	10.703	73.0	34.3	439	12.7	0.28	9.2	217

[a] For P, K, Ca, N, organic matter.

* Significantly different ($P = 0.05$) from exposed samples.

TABLE 5. Mean values of chemical and physical properties of soils with different degrees of burn.

Plot group and type of burn	Permeability	Liquid-solid contact angle	P	K	Ca	N	Organic matter	Sample size[a]
	kg/cm²	*degree*	*ppm*	*ppm*	*meq/100 g*	*percent*	*percent*	*number*
Plot group with >25 percent moderate + severe burn								
Unburned	0.752	77	229	641	14.4	0.32	13.8	24
Light	0.703	75	400	680	18.0	0.36	15.7	23
Moderate	0.703	71	423	650	18.4	0.34	12.6	20
Severe	0.639	73	325	520	17.4	0.30	15.6	15
Plot group with <25 percent moderate + severe burn								
Unburned	0.864	72	303	360	11.0	0.28	13.4	18
Light	0.604	68	349	360	11.9	0.34	16.5	18
Moderate	0.773	76	270	309	8.2	0.25	13.9	16
Severe	0.899	69	290	353	4.8	0.14*	7.1	8
Thinned plot group								
Unburned	0.492	63	283	470	14.5	0.32	17.3	14
Light	0.653	77	295	469	15.6	0.26	10.4	14
Moderate	0.555	68	405	517	17.9	0.33	15.7	12
Severe	([b])	71	263	566	21.4	0.18	8.5	3
Unthinned plot group								
Unburned	0.787	73	343	682	15.6	0.31	7.6	22
Light	0.695	74	361	657	17.4	0.34	8.9	21
Moderate	0.738	73	323	666	19.5	0.30	6.2	17
Severe	0.590	71	385	747	18.5	0.23	13.2	12
Ceanothus plot group								
Unburned	0.773	75	252	319	9.9	0.36	6.8	20
Light	0.632	71	386	358	12.6	0.40	10.6	19
Moderate	0.808	82	281	360	11.8	0.36	6.0	16
Severe	0.780	73	353	415	14.0	0.29	7.2	11
No *Ceanothus* plot group								
Unburned	0.710	77	275	761	15.0	0.31	12.6	16
Light	0.611	74	333	808	18.6	0.34	13.9	16
Moderate	0.569	68	272	734	16.9	0.31	9.8	14
Severe	0.632	72	297	505	12.8	0.23	13.1	11

[a] For P, K, Ca, N, organic matter.

[b] Data insufficient for analysis.

* Significantly different ($P = 0.05$) from other burn types in this plot group.

Cation levels did not differ significantly among the various burning treatments in either soil group 1 or 2 (Table 3), which may be a consequence of leaching. However, it also points to the importance of litter fall for replenishment of nitrogen and organic matter in the soil, a possibility supported by the significant difference of cation levels between severely burned soil sampled under upturned logs and in locations more exposed to litter fall and precipitation (Table 4). That disparity led us to exclude the data from soils sampled under upturned logs from analyses that contrasted intensity of burn.

Nitrogen levels differed significantly between burned and unburned soils when intensity of burn was compared between plots with large and small areas of combined moderate and severe burn (Table 5) and when burned members of the

TABLE 6. Values of chemical and physical properties averaged for pooled light, moderate, and severe burn samples of burned and unburned soils in the three plot groups.

Plot group	Permeability	Liquid-solid contact angle	P	K	Ca	N	Organic matter	Sample size
	kg/cm^2	*degrees*	*ppm*	*ppm*	*meq/100 g*	*percent*	*percent*	*number*
>25 percent vs. <25 percent moderate + severe (M + S) burn								
Burned plots								
>25 percent M + S burn	0.688	73	38	628**	18.0**	0.34**	14.6	12
<25 percent M + S burn	0.710	71	31	306	8.3	0.25	12.9	8
Unburned plots paired with plots having								
>25 percent M + S burn	0.752	77	29	641	14.4	0.32	13.8	12
<25 percent M + S burn	0.864	71	29	338	9.9	0.27	12.9	8
Thinned vs. unthinned plots								
Burned plots								
Thinned	0.604	73	337	499	17.1	0.28	12.4	7
Unthinned	0.695	73	330	640	17.3	0.31	12.6	9
Unburned plots								
Thinned	0.492	63	283	470	14.5	0.32	17.3	7
Unthinned	0.787	73	343	682	15.6	0.31	10.7	9
Ceanothus vs. no *Ceanothus*								
Burned plots								
Ceanothus	0.717	75	376*	372**	12.6*	0.36	17.9**	10
No *Ceanothus*	0.604	71	302	702	16.5	0.30	12.3	8
Unburned plots paired with plots having								
Ceanothus	0.773	75	262	319*	9.9*	0.30	15.8	10
No *Ceanothus*	0.710	77	275	761	15.0	0.31	12.6	8

* Significantly different ($P = 0.05$).

** Significantly different ($P = 0.01$).

plot pairs were compared by burn area, thinning, and *Ceanothus* cover (Table 6). Our data in Tables 4 and 6 suggest that some effects of burning on cation status may still be noticeable after 25 years. However, we are uncertain whether these differences demonstrate long-term effects of burning or whether they result from rearrangement of the data.

Burning did not seem to have long-term effects on phosphorus levels in our plots. However, burning may have indirectly affected phosphorus levels and soil content of organic matter on those plots where it stimulated germination and growth of *Ceanothus* species. Amounts of phosphorus and organic matter were significantly higher on burned plots with *Ceanothus* than on burned plots without *Ceanothus* (Table 6). Higher levels of calcium and potassium on the burned plots without *Ceanothus*, compared to the burned plots with *Ceanothus*, probably do not reflect any effects of burning. We assume this because levels of potassium and calcium are also significantly higher on the paired unburned plots without *Ceanothus* than on unburned plots with *Ceanothus*. The absence of *Ceanothus* from sites with significantly higher levels of potassium and calcium could indicate that *Ceanothus* competes better on sites with lower fertility.

Our analyses (Tables 2–6) failed to show that burning had any long-term effects on permeability and wettability of soils. Tarrant (1956) showed that heavy burning decreased infiltration rates in forest soils of the Pacific Northwest, but he gave no clues for how long after burning this condition lasts. Our data suggest that forest soils in the Pacific Northwest regain their original infiltration capacity within <25 years.

The work of Dyrness (1976) suggests that water repellency of soils caused by burning does not persist for long periods. Our results tend to confirm his findings. Unfortunately, his data were unavailable to us when we sampled. Our samples were only from the top 10 cm of soil; however, Dyrness found the most repellent layer below this depth. Consequently, we cannot entirely rule out the possibility of long-term effects of burning on wettability at some greater depth. Our findings indicate a lack of detrimental long-term effects of broadcast slash burning on nutrient status and physical properties of forest soils in the western Cascade Mountains of Oregon and Washington. This assumes that soil properties of the plot pairs were comparable *before* burning and that lack of significant differences between burned and unburned plots indicate a return of burned plots to their condition before burning. We could more conclusively interpret our data if soil had been analyzed before burning to provide actual base data.

LITERATURE CITED

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